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PB-250 000

ENERGY DEVELOPMENT: THE ENVIRONMENTAL TRADEOFFS

VOLUME 1: SUMMARY OF VOLUMES 2-4

STANFORD RESEARCH INSTITUTE

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

NOVEMBER 1975

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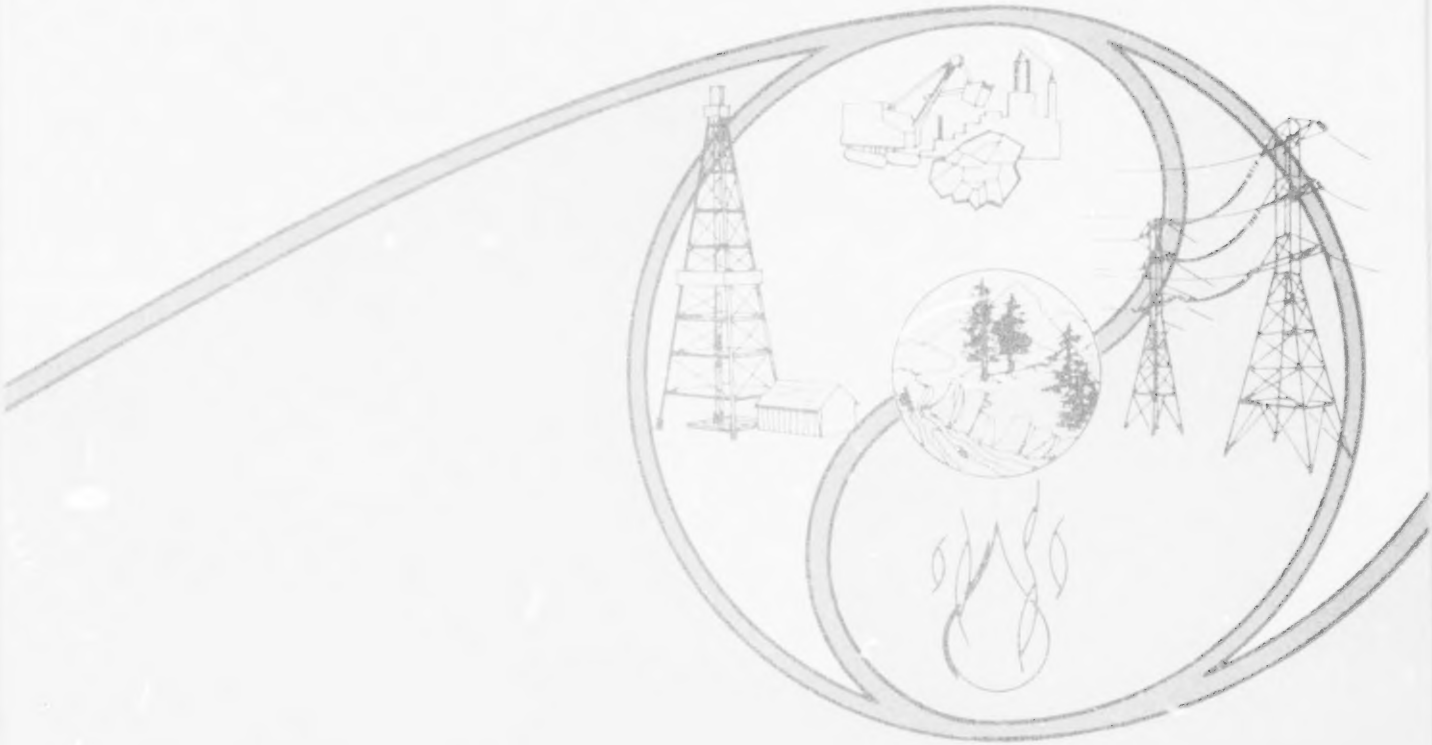
ENERGY AND ENVIRONMENT SERIES

ENERGY DEVELOPMENT: THE ENVIRONMENTAL TRADEOFFS

VOLUME 1: SUMMARY OF VOLUMES 2-4



prepared for

OFFICE OF PLANNING AND EVALUATION
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

29

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Energy Development: The Enviornmental Tradeoffs Volume 1: Summary of Volumes 2-4			5. Report Date November 1975 6.
7. Author(s)			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Stanford Research Institute Menlo Park, CA 94025			10. Project/Task/Work Unit No. SRI Proj No.3563 11. Contract/Grant No. 68-01-2469
12. Sponsoring Organization Name and Address Office of Planning and Evaluation U.S. Enviornmental Protection Agency Washington, DC 20460			13. Type of Report & Period Covered 14.

15. Supplementary Notes

Energy and Environment Series

16. Abstracts

This summary report is the first volume of four in the series "Energy Development: The Enviornmental Tradeoffs."
This volume provides a brief summary of volumes 2 through 4 of the series. The background papers include: technical overview; social impacts of energy development in a rural area: a case example of western coal development; water availablity and consumption for energy; water pollution potential of energy converstion processes; and air pollution impacts of energy processes.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

i

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
unlimited	UNCLASSIFIED	29
	20. Security Class (This Page) UNCLASSIFIED	22. Price $4.00-2.25

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

November 1975

ENERGY DEVELOPMENT: THE ENVIRONMENTAL TRADEOFFS

Volume I SUMMARY OF VOLUMES 2-4

Prepared for:
OFFICE OF PLANNING AND EVALUATION
U.S. GOVERNMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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CONTRACT NO. 68-01 2469
SRI PROJECT NO. 3563

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PREFACE

This summary report is the first volume of four in the series "Energy Development: the Environmental Tradeoffs." These reports have been prepared for the Office of Planning and Evaluation of the U.S. Environmental Protection Agency to clarify issues related to critical environmental tradeoffs among options to increase domestic energy production. The reports are designed to provide an initial assessment of factors that can influence policymakers and interested citizens in their ranking of energy supply options with respect to environmental and social impacts. The four volumes of this study should be read with full understanding that this assessment process is in its early stages and that much more data and analysis are needed before firm judgments can be supported. These reports are issued in the anticipation that they will contribute to useful and enlightened debate on the relative environmental impacts of alternative methods of energy resource extraction and conversion.

This volume provides a brief summary of Volumes 2 through 4 of the series. Volume 2 consists of an environmental tradeoff analysis for three sets of options to increase domestic energy supply. The three sets include: four options to produce electricity from western coal for use in the Midwest; seven options for producing crude oil; and four options to produce pipeline quality gas. Volume 3 investigates the relative environmental impacts of oil spills in ten proposed offshore continental shelf areas. Volume 4 consists of background papers directly relevant to the issues analyzed in Volumes 2 and 3. The background papers include: technical overview; social impacts of energy development in a rural area: a case example of western coal development; water availability and consumption for energy; water pollution potential of energy conversion processes; and air pollution impacts of energy processes.

ACKNOWLEDGMENTS

The four volumes of the study "Energy Development: the Environmental Tradeoffs," of which this is the summary volume, involved a multi-disciplinary team of SRI researchers. Mark D. Levine was project leader. Supervisory assistance was provided by Robert M. Rodden, director of the Operations Evaluation Department at SRI, and Stephen L. Brown, SRI environmental program manager. The researchers who collaborated in the study and who wrote parts of one or more volumes include Robert V. Steele, Irving W. Yabroff, Patrick J. Kinney, Steven H. Traver, Phillip D. Carpenter, and Mark D. Levine. The authors gratefully acknowledge the assistance of many colleagues in the Operations Evaluation Department, especially Buford R. Holt, Barry L. Walton, and Kristin M. Clark. Larry H. Oppenheimer, the EPA project officer, provided valuable critiques and insights throughout the investigation. John Butler of EPA made valuable suggestions in the later stages of the research effort. Typing above and beyond the call of duty was accomplished by Madeline J. Anderson. The editing was performed by Phyllis F. Dorset.

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SUMMARY

A. Objectives of the Study

The objectives of the study were to

- Highlight the key environmental problems of increasing U.S. energy production
- Indicate critical environmental tradeoffs among options to increase energy production
- Provide a basis for ranking energy supply options with respect to their relative environmental and social impacts.

The study has been prepared for decision makers, stakeholders affected by energy development, and informed citizens. The report is designed to provide a framework within which rational debate about the environmental consequences of alternative methods of increasing energy supply can occur. No "final" ranking with respect to environmental values is established in the report; analysis and best judgment are used to support a tentative ordering of the energy options.

B. Scope of the Study

Four sets of options were evaluated with respect to their relative environmental and social impacts. The analysis was performed using the same methodology for three of these sets of options:

1. Options for the Development and Use of Western Coal for Electricity Generation

   a. Direct electricity generation on-site; transmission to the Midwest.

   b. Low-Btu gasification on-site; combined cycle electricity generation; transmission to Midwest.

   c. Coal transport to Midwest by rail; direct electricity generation in Midwest.

   d. Coal transport to Midwest by rail; low-Btu gasification in Midwest; combined cycle electricity generation.

2. Options for Increasing U.S. Oil Production

   a. Liquefaction of midwestern coal in the Midwest.
   b. Liquefaction of western coal in the West.
   c. Production of synthetic crude oil from oil shale.
   d. Oil from the outer continental shelf (Mid-Atlantic OCS).
   e. Oil from onshore Alaska.
   f. Assisted recovery of oil--micellar flood and CO_2 miscible methods.
   g. Assisted recovery of oil--steam injection methods.

3. Options for Increasing Pipeline Quality Gas Supply

   a. Mining of western coal, gasifying it on site, and piping it to the Midwest.
   b. Mining of midwestern (Illinois) coal and gasifying it near the site.
   c. Producing gas from wells at offshore locations (Atlantic and southern California OCS) and piping it ashore.
   d. Producing gas from wells in Alaska, liquefying it, and shipping it to the West Coast via liquefied natural gas tankers.

A fourth set of options was assessed with respect to only one environmental variable: the relative environmental impact of oil spills in different regions. This set is:

4. Options for Producing Oil in the Offshore Continental Shelf

   a. North Atlantic
   b. Mid-Atlantic
   c. South Atlantic
   d. Santa Barbara Channel
   e. South of the Channel Islands (California)
   f. Gulf of Alaska
   g. Bristol Bay (Alaska)
   h. Beaufort Sea (Alaska)
   i. Cook Inlet (Alaska)
   j. Kotzebue Sound (Alaska).

C. Methodology

The essential analytical problem of this study is that of developing information that can form the basis for judgments about the relative merits of different methods of energy production based on environmental considerations. Three considerations were especially important in the formulation of the methodology: (1) the need to exclude value judgments from a portion of the analysis to establish an essentially "value-free" data base, (2) the need to make explicit the value judgments that entered the analysis, and (3) the practical need to evolve an approach to permit comparison of critical tradeoffs of energy production options so that conclusions could be reached. What follows is a summary of the key steps that have been developed to fulfill these criteria. These steps are the main elements of the methodology used for the first three sets of options.*

1. Selection of Options for Increasing Energy Supply

a. Limitation of the Analysis to Fossil Fuels

The selection of measures to increase energy supply was limited to the production of fossil fuels. The fossil fuel options were chosen to illustrate the range of expected environmental problems based on EPA's judgments about (1) new energy augmentation measures most likely to contribute to domestic energy supply within the next two decades and (2) measures for which relative environmental tradeoffs are not adequately understood. No attempt was made to include nonfossil fuel alternatives such as nuclear power.

b. Comparison of Options which Produce Energy of the Same Form

Environmental comparisons are made only among options which produce the same end product. It is beyond the scope of the analysis to

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*The reader is referred to Volume III of this report for a discussion of the methodology established to assess the relative environmental impacts of oil spills in the different offshore regions.

compare the environmental impacts of generating electricity with those of producing oil, for example. Tradeoffs other than environmental ones will play a major role in any analysis of the production of different energy forms. The perceived need of the nation for oil to provide protection from uncertain foreign sources is relevant to the analysis of alternative uses of western coal, as are a host of other similar considerations, such as regional patterns of energy demands for different forms of energy.

The problem of comparing diverse social benefits is avoided by restricting the comparisons to those between different options which produce energy of the same form. For these comparisons, the end uses can be considered identical and thus factored out of the analysis. We suggest that some of the conceptual problems of prior work in which comparisons among fuel types have been made were the result of a lack of appreciation of the nature of the problems that arise in attempting to make interfuel comparisons.

2. Selection of Environmental Indicators

Two objectives dominated our selection of environmental indicators: (1) the need to encompass a variety of environmental effects of diverse technologies and development activities, and (2) the desire to limit the number of indicators to facilitate communication of the results and to keep the analysis within manageable bounds. To balance these two objectives, we have defined seven environmental indicators to reflect physical alterations of the environment, human health effects, resource depletion (specifically, water depletion), and social impacts:

a. SO_2 impacts on air quality
b. NO_x impacts on air quality
c. Particulate impacts on air quality
d. Population
e. Aesthetics/land use
f. Water consumption relative to availability
g. Water quality.

3. Determination of Impacts of Energy Supply Options

For each of the seven indicators, quantitative estimates of the impacts were made wherever possible. We assumed the application of state-of-the-art control technology, or of control technology adequate to meet current environmental regulations. We also surveyed industry plans, engineering designs, and independent evaluations to determine the applicability of the assumptions regarding the efficiency of control technologies and the likelihood of their implementation.

4. Ranking of Energy Supply Options

For each of the options to be compared with one another, relative rankings were established with regard to the seven environmental indicators. The rankings, which ranged from "least adverse" to "intermediate" to "most adverse," were determined on the basis of both the quantitative impacts and relevant qualitative considerations. The inclusion of qualitative factors is an essential ingredient of the ranking methodology. For example, equal quantities of emissions to the air of the same technology located in two different areas can have vastly different human health impacts, depending on background levels of air pollution in the areas, the density and composition of nearby populations, topography, etc. This example illustrates the need for a broad assessment of factors that are difficult to quantify (and whose quantification is beyond the scope of the study) to arrive at appropriate rankings. In all instances, the ranking was based on an assessment of the impacts of an option relative to the other options. No attempt was made to establish a ranking based on an absolute level of impact.

5. Analysis of Critical Tradeoffs

Once all of the options within a given set were ranked for each of the environmental indicators, there was the difficult problem of assessing all of this information to arrive at relative judgments about the overall impacts of the options. The first step was to summarize the relative advantages and disadvantages of the options in a pro/con type of discussion. This made possible the delineation of the critical environmental tradeoffs differentiating the options. The analysis, if only

carried to the point of focusing attention on the critical tradeoffs, was valuable in defining the key issues that should be addressed by environmental research and analysis. We extended the analysis by seeking to indicate dominance among the options with regard to the number and severity of "most adverse" and "least adverse" rankings.

D. Principal Findings for Western Coal Options

Option 1: Direct electricity generation on-site; transmission to Midwest

Advantages

- Cost of electricity is less than for low-Btu gasification (Options 2 and 4) and is approximately equal to direct burning after transport to the Midwest (Option 3).

Disadvantages

- Population impacts in the West are substantially greater than for options that transport coal to the Midwest.
- Water consumption is large in an area that has limited water resources. With an increase of as much as 20 percent to the cost of electricity, dry cooling can be used to eliminate this disadvantage.
- Land use requirements, due to transmission corridors to the Midwest, are much larger than required for options that export coal from the West.
- NO_x emissions are high; in certain locations they can contribute to oxidant formation.

Option 2: Low-Btu gasification on-site; combined cycle electricity generation; transmission to Midwest

Advantages

- Ambient SO_2 levels are less than 25 percent of the direct coal burning levels (Options 1 and 2).
- Ambient NO_x levels are less than 4 percent of levels from direct burning (Options 1 and 3). The potential for photochemical oxidant formation is greatly reduced from that of the direct-burning options.

- Particulate emissions and resulting ambient air levels are substantially smaller than for direct burning if advanced gasification technology is used.

Disadvantages

- Population impacts in the West are greater by a factor of 10 or more than for options that transport coal to the Midwest (Options 3 and 4) and greater by a factor of 3 than for direct burning on-site (option 1).
- Consumption of western water is the greatest of the four options.
- Land use impacts due to transmission corridors to the Midwest are large.
- Cost of electricity, on the basis of current low-Btu gasification technology, is significantly higher for gasification processes than for direct burning of coal.

Option 3: Coal transport to Midwest by rail; direct electricity generation

Advantages

- Urbanization impact on West is minimal.
- Consumptive use of water in the West is small.
- Land use impacts are reduced as present rail lines are substituted for new transmission lines.
- Cost of electricity is lower than for low-Btu gasification options.

Disadvantages

- SO_2 emissions are the highest of the options (2-1/2 times greater than on-site gasification). These emissions occur near heavily populated areas already subject to high levels of SO_2 and sulfates.
- NO_x emissions are high (approximately equal to comparison federal standards).
- Particulate emissions are high.

Option 4: Coal transport to Midwest by rail; low-Btu gasification; combined cycle electricity generation

Advantages

- Urbanization impact on West is minimal.
- Consumptive use of water in the West is small.
- SO_2 emissions are low.
- NO_x emissions are low; potential for formation of photochemical oxidants is low.
- Land use impacts are reduced.

Disadvantages

- Cost of electricity on the basis of current low-Btu gasification technology is significantly higher than for direct burning of coal.

E. Conclusions for Western Coal Options

Figure 1 summarizes the environmental advantages and disadvantages of the four options for producing electricity from western coal. Caution must be exercised in interpreting Figure 1. It would be incorrect to conclude that the options with the smallest number of "most adverse" and the largest number of "least adverse" rankings are necessarily those that are most desirable from an environmental point of view. The reason for this is that (1) the relative importance of the different environmental impact categories has not been established in this study (e.g., is a "most adverse" SO_2 ranking more or less important than a "most adverse" population impact ranking?) and (2) Figure 1 does not consider the degree to which the environmental costs and benefits are equitably distributed among the population affected by the production of electricity. We have hitherto excluded these two factors from the analysis because they are both heavily laden with value judgments. We now include these subjective factors in the analysis of the two relative rankings among the four western coal options.

1. Establishing the "Least Adverse" Option

We first analyze Figure 1 to determine if any options exhibit dominance in the rankings relative to the remaining options. Dominance of rankings is achieved for Option 4, combined cycle in the Midwest, which

	SO_2 Impacts	NO_x Impacts	Particulate Impacts	Population Impacts	Aesthetic/Land Use	Water Consumption Rel. to Availability	Water Quality
1 Direct Burning in West	0	−	0	−	−	−	0
2 Combined Cycle in West	+	+	+	−	−	−	0
3 Direct Burning in Midwest	−	−	−	+	+	+	0
4 Combined Cycle in Midwest	+	0	0	+	+	+	0

+ = LEAST ADVERSE IMPACT 0 = INTERMEDIATE IMPACT − = MOST ADVERSE IMPACT

FIGURE 1. ENVIRONMENTAL TRADEOFF MATRIX FOR OPTIONS TO INCREASE ELECTRICITY PRODUCTION FROM WESTERN COAL

is ranked either "least adverse" or "intermediate" in impact for all impact indicators. We thus establish a ranking independent of subjective values ascribed to the relative importance of the impact indicators or to the issue of equity and conclude that

- Option 4, combined cycle in the Midwest, has the least adverse environmental impact of the four options.

Based on this analysis, we recommend that research and development for low-Btu gasification/combined cycle operations is worthy of high-level effort because of the expected environmental benefits of the technology. A successful R&D program would strive to improve the efficiency of low-Btu gasification combined cycle operation to increase its commercial desirability.

2. Establishing the "Most Adverse" Option

Option 1, direct burning in the West, has "most adverse" impacts for four indicators and no "least adverse" impacts. Options 2 and 3 each have three "least adverse" and three "most adverse" impacts. It is possible to conclude that Option 2, combined cycle in the West, is environmentally

preferable to Option 1, since they share equivalent "most adverse" rankings and Option 2 is favored in each of the remaining categories (the air pollution impacts).

Comparison of Options 1 and 3, siting steam electric power plants in the West and Midwest, respectively, is more difficult. Population, aesthetic/land use, and water consumption impacts favor siting in the Midwest. Rankings for the impact of SO_2 and particulate emissions on human health favor siting in the West. Value judgments between adverse social impacts in the West and adverse health impacts in the Midwest are difficult to reach and are likely to depend on the person making the judgment. A more nearly equitable distribution between the costs and benefits of the electricity generation is achieved by siting in the Midwest, near the population benefiting from the electricity generation.

It is our tentative judgment that

- The siting of steam electric power plants in the Midwest (Option 3) is environmentally preferable to the siting of steam electric power plants in the West (Option 1). This makes Option 1 the most adverse of the options.

This judgment is derived from equity considerations, which favor siting in the Midwest, as well as from the recognition that (1) population impacts are potentially able to cause substantial degradation in the quality of life in resource-rich areas of the West (see Volume IV, Chapter III) and (2) air pollution impacts in the Midwest might be controlled either by careful site selection or by reducing emissions from existing sources when new power plants are installed.

Additional analytical work is needed to subject this tentative judgment to critical evaluation. Such a study would compare the feasibility and cost of siting power plants in the Midwest so that air pollution health impacts are minimized with the feasibility and cost of reducing undesirable social impacts and minimizing water consumption of power plants sited in the West.

3. Differentiating Among "Intermediate" Impact Options

No attempt is made to rank Option 2, combined cycle in the West, relative to Option 3, direct burning in the Midwest. The tradeoff analysis

establishes no dominance among the ranking categories between the two options. Any choice among these options requires a heavy dose of value judgment. Resolution of the question of relative environmental cost of these two options probably requires that site-specific analyses be undertaken.

F. Principal Findings for Crude Oil Options

Option 1: Liquefaction of midwestern coal in the Midwest

Advantages

- Population impact is small; additional labor force can be largely supplied by present population.
- Water relative to additional demand is abundant.
- Water quality impact is small if proper treatment and recycling are carried out.

Disadvantages

- SO_2 and particulate impacts on air quality are significant in a densely populated area.

Option 2: Liquefaction of western coal in the West

Advantages

- Water quality impact is small if proper treatment and recycling are carried out.

Disadvantages

- There is potential for rapid population of sparsely populated areas, especially if the industry is geographically concentrated, e.g., the Powder River Basin.
- Water requirements are large relative to availability and could threaten instream flows or reduce availability for other uses, such as agriculture.
- NO_x emissions are large--potential for photochemical oxidant formation.
- There is potential for long-term land disruption due to strip mining of the land, which is difficult or impossible to reclaim.

Option 3: Production of crude oil from oil shale

Advantages

- Water quality impact is small if measures are taken to prevent leaching of spent shale piles into aquifers and streams and if depletion of upper Colorado is not excessive.

Disadvantages

- Social impacts are high due to a large influx of workers and families into a sparsely populated, geographically concentrated region.
- Water consumption is high in a water-poor region.
- SO_2, NO_x, and particulate emissions are at high levels.
- A significant amount of land is disrupted due to disposal of spent shale in canyons.

Option 4: Oil from the Mid-Atlantic OCS

Advantages

- Water consumption is negligible.
- SO_2, NO_x, and particulate emissions are insignificant.

Disadvantages

- There is potential for serious land use impacts if onshore development occurs in undeveloped coastal regions.
- Water quality is degraded due to chronic leakage and accidental spillage of oil.

Option 5: Oil from onshore Alaska

Advantages

- Water consumption is negligible.
- SO_2, NO_x, and particulate emissions are insignificant.

Disadvantages

- Social impacts are large due to influx of workers and their families into Alaska to build additional pipeline and port facilities.

- Water quality degradation probability is high due to increased tanker traffic in heavily traveled zones--includes both high risk of collisions in addition to increased routine discharges.
- Land is disrupted due to additional drilling and construction in permafrost regions, laying of new pipelines in remote wilderness areas, and so forth.

Option 6: Assisted recovery of oil-miscible methods

Advantages

- Social impacts are few.
- Existing water supplies are not strained.
- SO_2, NO_x, and particulate emissions are negligible.
- Additional land use is small due to development in existing fields.
- Water quality degradation probability is low.

Disadvantages

None.

Option 7: Assisted recovery of oil-steam injection method

Advantages

- Social impacts are few.
- Water quality degradation probability is low.
- Additional land use is small.

Disadvantages

- SO_2 and particulate emissions are significant if controls are not required.
- Water supplies in semiarid regions are potentially strained.

G. Conclusions for Crude Oil Options

Analysis of Critical Tradeoffs

Figure 2 is a matrix summary of the advantages and disadvantages discussed in the previous section. The figure indicates a dominance of

	Urbanization	Water Consumption Rel. to Availability	SO_2 Emissions	NO_x Emissions	Particulate Emissions	Aesthetics/Land Use	Water Quality
Midwest Coal Liquefaction	+	+	−	o	−	o	+
Western Coal Liquefaction	o	−	o	−	o	o	+
Oil Shale	−	−	−	−	−	−	+/o
OCS Oil (Atlantic)	o	+	+	+	+	o	−
Onshore Alaskan Oil	−	+	+	+	+	−	−
Assisted Recovery-Miscible Methods	+	+	+	+	+	+	+
Assisted Recovery-Steam Injection	+	o	−	−	−	+	+

+ = LEAST ADVERSE IMPACT

o = INTERMEDIATE IMPACT

− = MOST ADVERSE IMPACT

FIGURE 2. ENVIRONMENTAL TRADEOFF MATRIX FOR OPTIONS TO INCREASE DOMESTIC OIL SUPPLIES

"most adverse" rankings for oil shale and of "least adverse" impacts for assisted recovery using miscible methods. Because of the degree of this dominance in the rankings for these two options, we are led to conclude that:

- Oil shale, using present technology, is ranked the most environmentally degrading of the options to increase oil production.
- Miscible methods of assisted recovery are ranked the least environmentally degrading of the options.

Establishing rankings for the intermediate five options for increasing oil production is a complex task. The intermediate rankings depend on the relative importance one ascribes to the key adverse impacts and on the evaluation of the distribution of costs between beneficiaries and non-beneficiaries of the increased supply of oil. Placing a high value on an equitable distribution of social costs and benefits is equivalent to raising the rankings of coal liquefaction in the Midwest, OCS oil production in the Atlantic, and assisted recovery by steam injection (especially in California) since these options cause those who use the oil to suffer the adverse impacts of production. Similarly, valuing equity highly would lower the rankings of oil shale, onshore Alaskan oil, and coal liquefaction in the West since these options cause adverse impacts on others than those who are the primary beneficiaries of the increased oil supply.

Table 1 presents rankings for the seven oil supply options under five different "value judgment" assumptions: (1) all impacts are of equal importance, (2) social equity is of great importance, (3) social impacts are of great importance, (4) air pollution impacts are of great importance, and (5) oil spill impacts are of great importance. In all cases, we have made reasonable assumptions about the meaning of the term "great importance" in determining the ranking categories. The options are grouped into one of four relative ranking categories: "most favorable," "favorable," "less favorable," and "least favorable," with no distinction made among options within an individual category.

Table 1

PROBABLE RANKINGS OF THE OPTIONS TO INCREASE OIL SUPPLY
UNDER DIFFERENT VALUE JUDGMENTS

KEY ASSUMPTION	I: All impacts of equal importance	II: Social equity of great importance	III: Social impacts of great importance	IV: Air pollution impacts of great importance	V: Oil spill impacts of great importance
RELATIVE RANKINGS:					
Most Favorable	Assisted Rec.-misc.	same as I	same as I	same as I	same as I
	OCS Oil-Atl.	same as I	same as I	same as I	Coal Liq.-W
Favorable	Coal Liq.-MW	same as I	same as I	---	same as I
	Alaskan Oil	Ass'd Rec.-steam	same as II	same as I	same as II
	Ass'd Rec.-steam	Alaskan Oil	same as II	same as I	same as II
Less Favorable	Coal Liq.-W	same as I	same as I	same as I	OCS Oil-Atl.
				Coal Liq.-MW	
Least Favorable	Oil Shale	same as I	same as I	same as I	same as I

Table 1 shows that for the value judgment assumptions made, the rankings change very little. The "base case" ranking, for which all impacts are assumed to have the same value, is presented in Case I of Table 1. If one chooses to stress social equity (Case II), the assisted recovery by steam injection and Alaskan oil change places in the ranking categories. All other options remain unchanged in their rankings. Placing a high value on social impacts (Case III) yields identical rankings as Case II. Emphasizing the impact of air pollution (Case IV) results in only one change in the "base case" ranking, coal liquefaction in the Midwest is moved from the "favorable" to the "less favorable" ranking category. Only for Case V, in which a high importance is ascribed to oil spills, do the rankings change significantly. As we have indicated, our best judgment does not support assigning a high value to oil spill impacts.

We thus conclude that the rankings shown in Cases I through IV of Table 1 may be used to indicate the relative environmental impacts of the seven options to increase oil supply. Under a range of assumptions, oil shale receives the "most adverse" ranking and assisted recovery by miscible methods, the "least adverse" ranking. For the four different sets of assumptions in Cases I through IV, OCS oil was ranked "favorable." In three of the four cases, midwestern coal liquefaction was "favorable," and in one case, "less favorable." Alaskan oil and assisted recovery were "favorable" in two cases, and "less favorable" in two cases. Western coal liquefaction was "less favorable" in all four cases.

H. Principal Findings for Pipeline Quality Gas Options

Option 1: Mine western coal, gasify it on-site, and pipe it to the Midwest

Advantages

- Water quality degradation potential is small.
- SO_2 emissions are low compared to the equivalent federal performance standard.
- Particulate emissions are low if Lurgi technology is used in conjunction with low-Btu gas combustion.

Disadvantages

- Social impact potential is high due to heavy urbanization in sparsely populated areas.
- Water consumption is heavy in water-scarce regions.
- Long-term land disturbance potential is high.
- Significant particulate emissions are possible if Synthane or Hygas technologies are used with southwestern coal.

Option 2: Mine midwestern coal and gasify it near the site

Advantages

- Large-scale urbanization impact potential is low.
- Available water supplies are not strained.
- Water quality degradation potential is low.
- Land use impacts are small.

Disadvantages

- SO_2 emission levels are significant.

Option 3: Drill and produce gas at offshore locations (Atlantic and southern California OCS) and pipe it ashore

Advantages

- SO_2, particulate, and NO_x emissions are negligible.
- Water consumption is negligible.
- Water quality impact is small for production of nonassociated gas.

Disadvantages

- There is potential for biological disruptions in estuaries and wetlands due to pipeline construction.

Option 4: Drill and produce gas in Alaska, liquefy it, and transport it to the West coast via LNG tanker

Advantages

- SO_2 and particulate emissions are negligible.
- Water consumption is negligible.

Disadvantages

- Urbanization impact is large in coastal towns and along pipeline route.
- There is potential for significant land disturbance due to new pipeline construction.
- NO_x emissions are high.

I. Conclusions for Pipeline Quality Gas Options

The environmental rankings for the four options are summarized in Figure 3.

	SO_2 Impacts	NO_x Impacts	Particulate Impacts	Population Impacts	Aesthetics/Land Use	Water Consumption Rel. to Availability	Water Quality
Gasification in West	0	$\frac{+}{0}$	$\underline{0}$	−	−	−	+
Gasification in Midwest	−	0	0	+	+	+	+
OCS Gas (Atlantic & California)	+	+	+	0	$\underline{0}$	+	0
OCS Gas (Alaska)	+	−	+	−	$\underline{0}$	+	0

+ = Least Adverse Impact 0 = Intermediate Impact − = Most Adverse Impact

FIGURE 3. ENVIRONMENTAL TRADEOFF MATRIX FOR OPTIONS TO INCREASE PIPELINE QUALITY GAS PRODUCTION.

- The two most favorable options are the gasification of midwestern coal and the production of gas from the Atlantic and southern California OCS. For the gasification of midwestern coal, the only impact rated "most adverse" is the increased level of SO_2 emissions in the Midwest. The use of low-sulfur fuels within the gasification plants and judicious siting of the plants could reduce significantly both the level of emissions and the damage caused by them. For the production of gas from the OCS, the potentially important problem of wetland disruption due to the laying of platform-to-shore pipelines could be mitigated through careful planning of pipeline routes.
- Production of natural gas in Alaska and the gasification of western coal in the West are the two least favorable options for producing pipeline quality gas among the options considered. Gas production in Alaska is rated "most adverse" with regard to the high levels of nitrogen oxide emissions from gas liquefaction plants, the large influx of workers, their families and associated population into small Alaskan towns, and the potential for disturbing virgin areas through pipeline construction. Gasification of western coal in the West has "most adverse" impacts associated with the urbanization of rural areas, high levels of water consumption in water-scarce areas, and the surface mining of land that may be difficult to reclaim. There is also potential for significant degradation of air quality in parts of the West.

In the case of pipeline quality gas production, we conclude that the tradeoff issues are clearly defined and that the data we have presented provide a relatively sound basis for ranking. The rankings are generally independent of the value ascribed to the different impact categories and to the importance placed on issues of social equity, as thoughtful consideration of Figure 3 will indicate. We thus formulate the following two recommendations:

- Further research and development on technologies, such as the Synthane and Hygas processes, that can convert high-sulfur midwestern coal to low-sulfur gaseous fuel while minimizing SO_2 should be strongly emphasized.
- Before any large-scale development of western coal gasification or natural gas reserves in Alaska is carried out, substantial analysis and preplanning are required to reduce the impacts of urbanization and to fully assess and minimize the magnitude of environmental disruption.

J. Methodology for Assessing Impacts of Oil Spills in Different Regions

The methodology consists of factoring the offshore regimes into ecological components based on trophic levels and habitats. The components used were phytoplankton, zooplankton, benthic biota, shore-related biota, fish, marine mammals, and birds. Available biological and physical data were used to evaluate a series of factors expressing the relative sensitivity of each ecological compone o damage by oil (F_W); relative biological abundances (F_A); relative probabilities of major portions of the ecological component coming into contact with oil, given a spill (F_C); and relative probabilities of a spill occurring (F_S). All of these factors were evaluated on an arbitrary 1 to 7 scale of increasing effect. The factors are combined to arrive at an overall ranking for each area as to relative environmental risks due to oil spills. The method used simply forces a quantitative consideration of each important decision element.

K. Findings of Oil Spill Assessment

Table 2 presents the results of the assessment of factors contributing to increased probability and impacts of oil spills. The Gulf of Alaska, Cook Inlet (Alaska), and Bristol Bay (Alaska) offshore regions were judged most sensitive to the impacts of offshore development, primarily because of the high risk of spills due to earthquake and weather hazards, the abundance and sensitivity of shore and sublittoral species, and the relatively high abundance of marine mammals and birds. The offshore regions ranked intermediate with regard to potential environmental impacts of oil spills are the South Atlantic, the Beaufort Sea (Alaska), south of the Channel Islands (California), and the Santa Barbara Channel. The offshore regions judged least likely to suffer ecological damage due to oil spills are the North Atlantic, the Mid-Atlantic, and Kotzebue Sound (Alaska).

Table 2

ENVIRONMENTAL RANKING OF OCS REGIONS
(based on probability and impacts of oil spills)

OCS Region	Phytoplankton F_A	Phytoplankton F_w	Zooplankton F_A	Zooplankton F_w	Benthic Biota F_A	Benthic Biota F_w	Shore and Sublittoral F_A	Shore and Sublittoral F_w	Fish F_A	Fish F_w	Marine Mammals F_A	Marine Mammals F_w	Marine Birds F_A	Marine Birds F_w	Totals $\Sigma F_A \times F_w$	Rel. Prob. of Contact F_c	Rel. Prob. of Spills F_s	Total Impact $F_c F_s \Sigma F_A F_w$	Order of Ranking
Atlantic																			
N. Atlantic	5	1	4	2	4	1	6	6	7	1	3	3	6	6	93	3	2	558	1
M. Atlantic	5	1	4	2	4	1	6	6	6	2	2	3	4	6	95	3	3	855	2
S. Atlantic	4	1	4	2	4	1	7	6	4	2	2	3	6	6	102	5	3	1530	3
Southern California																			
(S. Calif. Bight)	(5)	1	(4)	2	(4)	1	(3)	6	3	1	5	4	3	6	78	6	4	1824	4
Santa Barbara Channel	7	1	4	2	5	1	3	6	(3)	1	(5)	4	3	6	79	6	4	1896	4
So. of Channel Is.	4	1	4	2	4	1	3	6	(3)	1	(5)	4	3	6	75	6	4	1800	4
Alaska																			
Gulf of Alaska	4	1	4	2	5	1	6	6	5	1	7	4	7	7	135	4	6	3240	6
Bristol Bay	3	1	4	2	3	1	5	6	(4)	2	6	3	6	7	112	6	4	2688	5
Beaufort Sea*	1	1	4	2	3	1	5	6	1	1	4	3	4	7	83	7	3	1743	4
Cook Inlet	3	1	4	2	2	1	4	6	(3)	2	6	3	6	6	88	6	6	3168	6
Kotzubue Sound	2	1	4	2	3	1	3	6	1	1	4	3	4	6	68	7	2	952	2

Note: Parentheses indicate estimates or extrapolations.

*Problem of albedo changes associated with oil in Arctic pack ice not considered: probability low but potential consequence great.

The responsible use of the results of the study should recognize the limited availability of information on biological abundances in different offshore regions and the need for site-specific analysis of plots within the general regions to determine local environmental sensitivities. The general findings stated above are, however, consistent with the best currently available information.